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Photoelectron Emission and Secondary Electron Emission Characteristics of Cesiated p-type GaN

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Abstract: *The emission characteristics of a cesiated p-type GaN sample are examined as a function of surface treatment, time following cesiation, and sample heating. The yield and energy distribution of both photoemitted electrons and secondary electrons are examined and correlated with the GaN surface properties.*

Keywords: photoemission; secondary electrons; GaN; negative electron affinity; photocathode.

Introduction

Sources for high-quality electron beams are needed for free electron lasers (FELs) and accelerator applications. Photocathodes have been predominantly used in such applications since they are the only traditional source capable of fast pulses (using a pulsed laser). High peak current and high efficiency are also possible, depending on the laser parameters and photocathode material properties. However, it is often difficult to achieve high speed, high quantum efficiency (QE), and long lifetime simultaneously from a given cathode material due to tradeoffs between laser properties and material response. Specifically, metals are typically very robust photoemitters but have low QE (< 0.01%) that may be unacceptable for increasingly demanding applications. Moreover, metals require incident UV photons to overcome the ~ 4 – 5 eV work function at the clean surface, but the efficiency of the drive laser is very low for such 4th-order harmonic light generation. While the work function can be reduced by sub-monolayer adsorption of alkali metal, this surface is very reactive and no longer provides for robust emission. On the other hand, semiconductors can provide very high QE (> 10%) as long as the photon energy is greater than the bandgap and the surface is coated with an alkali metal to produce a negative electron affinity (NEA) at the surface. While such NEA surfaces can be reasonably stable, especially in wide bandgap materials, such surfaces are still susceptible to damage from ion back bombardment as well as to gradual degradation from contamination and alkali metal desorption.

There is a clear need to develop a robust photocathode that provides high QE at the longest possible wavelength and allows for in-situ regeneration for long-lived operation. Our approach will focus on combining the best attributes of both semiconductors and metals in a photocathode structure. Specifically, a "dispenser" technology is envisioned that will allow alkali metal (e.g., cesium) to diffuse through a porous metal substrate and then across the surface of a semiconductor material in a controllable manner, thereby maintaining a NEA surface over time. As a first step, we are examining the emission characteristics and surface dynamics associated with cesiated surfaces of promising photocathode materials. One such material is GaN, which is a direct, wide bandgap (3.4 eV) semiconductor that has been reported to achieve a QE as high as 50% [1]. Our initial studies examine the emission characteristics of a cesiated p-type GaN sample as a function of surface treatment, time following cesiation, and sample heating. Our goal is to identify the optimum surface conditions needed for stable, uniform emission.

Experiment / Results

In this study, secondary electron emission measurements were taken from the GaN surface (using a 0-3 keV electron gun) prior to and after cesiation to characterize the surface electronic properties (i.e., work function, electron affinity), while Auger electron spectra were taken to characterize the chemical composition of the surface. Photoemission yield and energy distribution measurements were then obtained using a Nd:YAG laser with ~ 5 ns pulses operated at a maximum rep rate of 15 Hz. After cesiation, a series of measurements were taken to examine the stability of the surface and emission properties as a function of time and sample temperature.

In the secondary emission measurements, the maximum yields increased from 4 to 36 following cesiation, as seen in Fig. 1, where the yield is defined as the ratio of the emitted to incident electron current. The large increase in yield indicates good electron transport to the surface as well as a reduced barrier at the surface. In fact, energy distribution measurements revealed that the electron affinity decreased by at least 2 eV, with the emission originating from the bottom of the conduction band E_c. However, while the energy distribution became much sharper, it possessed a high-energy tail that seems to indicate incomplete thermalization or energy broadening during transport. This distribution is shown as the dashed curve labeled "e-gun" in Fig. 2, where the electron energy is measured relative to the Fermi level E_f. As measurements were taken in the weeks following cesiation, the maximum yield steadily decreased to ~ 13, while the electron affinity increased by ~ 1 eV. During this time, however, measurements of the

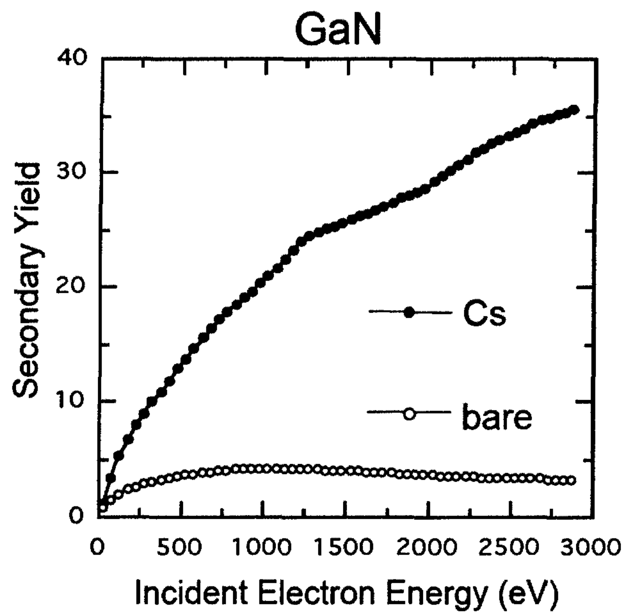

Figure 1. Secondary Yield Curves

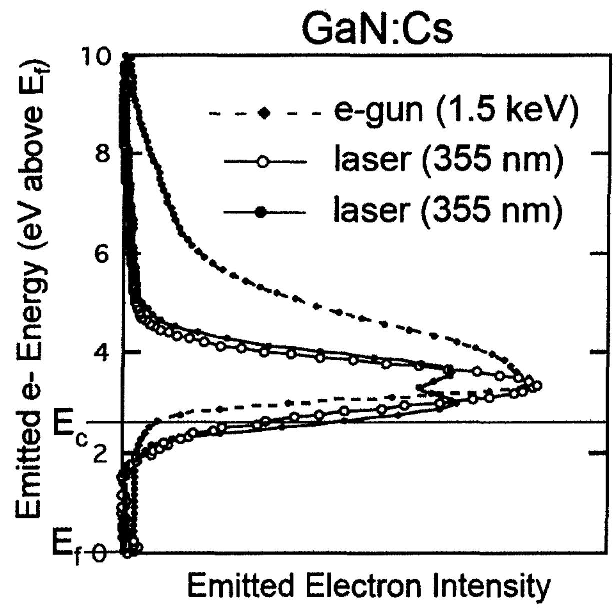

Figure 2. Energy Distribution Curves

relative Cs concentration on the surface changed very little. The mechanisms responsible for the apparent changes in the surface electronic structure and the resulting emission degradation must be identified.

In photoemission measurements taken from the cesiated GaN surface using 355 nm/3.49 eV photons, a very low QE was measured from the cesiated GaN surface in spite of the moderately high secondary yields measured from the same surface. However, the photocurrent increased by a factor of ~ 300 by shining a flashlight on the sample surface. We need to examine whether the low laser-induced QE is due to reflection/absorption issues or to transport/emission issues, and we need to understand the mechanism for the increased yield upon broad-spectrum illumination. On the other hand, the photoelectrons emitted from the cesiated GaN surface exhibited a narrower energy distribution, a lower emission-onset energy, and a smaller high-energy tail than detected in the secondary emission measurements. This is seen in the solid curves labeled "laser" in Fig. 2. However, in some measurements a single peak was present (open circles) while in others a double-peaked distribution was observed (filled circles). In the latter case, the two peaks exhibited different behavior in subsequent measurements, with the lower-energy peak remaining fairly stable while the higher-energy peak shifted upwards over time. The cause of this anomalous behavior needs to be better understood. Specifically, we need to examine whether other features (such as surface or gap states) are being probed by the laser and whether the pulsed nature of the laser is affecting the electron generation and transport processes in the material.

Summary

A negative electron affinity was produced at the p-type GaN surface following cesiation, resulting in a significant increase in the secondary electron yield. However, the energy distribution of emitted low-energy electrons was found to differ in photoemission and secondary emission measurements. Due to differences in the electron generation process, the photoelectrons had a substantially narrower energy distribution than the secondary emission electrons. However, the measurements revealed that the photoelectron distributions were not as uniform as the secondary electron distributions, with features appearing in some of the photoelectron spectra that appeared to be associated with different surface or bulk states.

References

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